Autonomous Systems for Potential Mine Warfare Applications – A Trend Analysis of Technologies 1997-2002

CDR Christopher L. Butler, USN
Office of Naval Research International Field Office - Europe
Ocean, Atmosphere and Space S&T Focus Area
223 Old Marylebone Road, London NW1 5TH
Tel. 44-171-514-4948, Fax. 44-171-514-4980
Email: mcm@onrifo.navy.mil
http://www.onrifo.navy.mil

Ocean, Atmosphere and Space S&T – MetOc Newsletter 02-10
Keywords: *Autonomous, Mines, Sensors, Systems, Platforms*

Autonomous Operations FNC/Organic MCM FNC/OE – Trend Analysis Report News Headlines -Trend analysis of open source autonomous technologies reveal evolutionary advances with an increasing trend in the number of scientists conducting research in higher order functionality in autonomous systems. The wider application and proliferation of this technology may accelerate the development of next generation asymmetric threats.

INTRODUCTION

Recently, the Office of Naval Research International Field Office provided an Autonomous Systems Trend Analysis summary to The Technical Cooperation Panel (TTCP) to highlight developments in critical emerging technologies applicable to Mine Countermeasures (MCM) and Mine Warfare (MIW). Generalizations of the areas of research focused on by Non-TTCP nations were characterized by analyzing articles published in open sources over the period of 1997-2002. Leading Non-TTCP nations focusing on autonomous technologies systems, and sensors, were identified, as well as leading centers of excellence, as potential partners in future research collaborations. For the analysis period, much of the research available in open sources that is related to the topic of Autonomous MIW systems is directed towards developments in robotics, image processing, control-theory, and sensor/data fusion. Although most advances were more evolutionary than revolutionary, an increasing trend exists in the number of scientists conducting research in higher order functionality in autonomous systems. The proliferation of autonomous technology, and widening applications may produce the next generation of asymmetric threats, such as autonomous mobile offensive mines, and new intelligent counter countermeasure. This Newsletter is designed to inform national and international scientists, research and governmental institutions and international organizations about perceived trends in autonomous technology that may have application in MCM and MIW systems.

LONG TERM GOALS

The long-term goals of these TTCP driven analyses are to:

1. Report on innovative international research initiatives (outside of the United States, United Kingdom, Australia, Canada, and New Zealand), applicable to mine countermeasures and MIW in general.
2. Mitigate technology surprise by highlighting revolutionary and evolutionary trends in autonomous and semi-autonomous systems and sensors based on perceived critical and emerging technologies.
3. Identify leading centers of excellence for potential science and technology research collaborations in areas identified as high interest work.

OBJECTIVES

This particular project is aimed at assessing trends in supporting technologies for autonomous systems that could be utilized in rapid environmental characterization, countermine operations, or defensive mining.

APPROACH

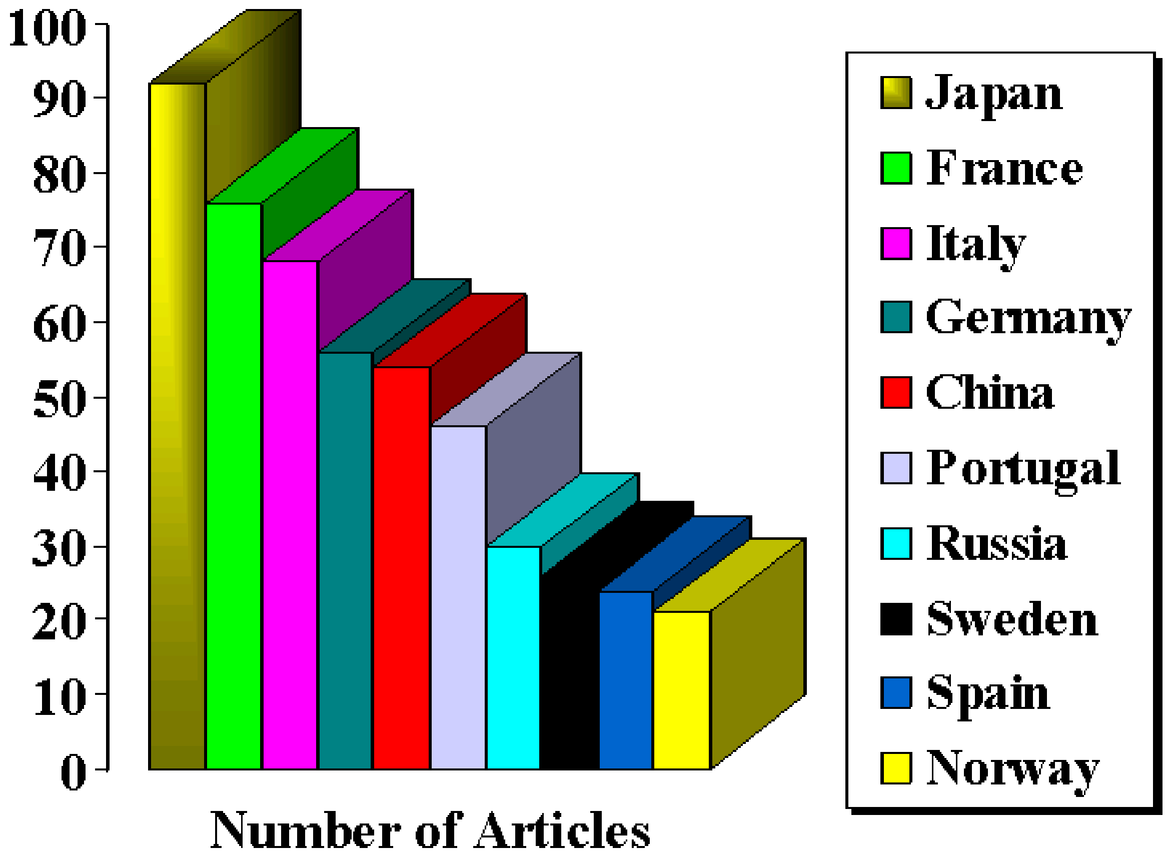
The Autonomous Mine Warfare systems Analysis Methodology consisted of:

1. Electronic text and data searches across supporting technologies.
    a. A general terms search (i.e., autonomous AND mines) was conducted over the Naval Research Laboratory's web access to the INSPEC database (633 records were returned). Details on the INSPEC database composition can be found at http://www.iee.org/publish/inspec/.
    b. The INSPEC database was also searched for specific keywords in Title (i.e., "New", "Innovative", "Original", OR "First") and cross-referenced with the general search.
    c. A Technology Opportunity Analysis System (TOAS) Factor Map of combined sources using low frequency descriptors was analyzed for Knowledge Discovery (see: http://www.searchtech.com/toas.htm for more information on TOAS).
    d. Various World Wide Web Search engines were investigated, (i.e., http://transit-port.net/Lists/AUVs.html, http://cdps.umcs.maine.edu/AUV/ and http://www.acim.louisiana.edu/acim/auvlist.html), and The Patent databases (i.e., http://www.european-patent-office.org/ was searched for Knowledge Discovery.Revelations from attending topic related conferences (i.e., ICAR2001, UDT, Oceanology International, and UUV Showcase), ONRIFO S&T Liaison Site Visits and feasibility studies for expanding ONR sponsored UUV Competitions into areas of International Robotic Competitions (i.e., RoboCup, The Rescue Robot Competition, and RobotWars) were included in this analysis.
3. General characterization of trends and knowledge discovery were made.

RESULTS

DATA MINING

While the TTCP countries account for the bulk of the open literature related to these areas of research (~75%), there are several other countries that contribute significant amounts of research material. The chart below depicts the results of data mining across autonomous mine warfare system supporting technologies. The Top Ten Non-TTCP countries publishing papers in open literature are Japan, France, Italy, Germany, China, Portugal, Russia, Sweden, Spain, and Norway.



Analyzing the top ten Non-TTCP nations verses the Top affiliations identified centers of excellence in research supporting autonomous mine warfare systems.

Author Affiliation (Cleaned)	# Records	Author Affiliation (Country)	1 Dept. of Electr. Eng., Inst. Superior Tecnico, Lisbon, Portugal	2 Fac. de Engenharia, Porto Univ., Portugal	3 Inst. of Ind. Sci., Univ. of Tokyo, Japan	4 Norwegian Defence Res. Establ., Kjeller, Norway	5 Inst. of Naval Archit. & Ocean Eng., Nat. Taiwan Univ., Taipei, Taiwa	6 Sch. of Naval Archit. & Ocean Eng., Shanghai Jiaotong Univ., China	7 Sch. of Electr. & Electron. Eng., Nanyang Technol. Univ., Singapore,	8 TNO Phys. & Electron. Lab., The Hague, Netherlands	9 Dept. of Underwater Acoust. Eng., Harbin Eng. Univ., China	10 Inst. Superior Tecnico, Lisbon, Portugal	11 Istituto per l'Autom. Navale, CNR, Genova, Italy	12 Inst. of Marine Technol. Problems, Acad. of Sci., Vladivostok, Russia	13 KDDI R&D Labs., Saitama, Japan	14 Lab. of Process. Control & Autom., Helsinki Univ. of Technol., Espoo	15 Norwegian Univ. of Sci. & Technol., Trondheim, Norway	16 Inst. of Inf. & Applications, Girona Univ., Spain	17 Signal & Image Centre, R. Military Acad., Brussels, Belgium	18 Underwater Robotics Dept., Groupe d'Etudes Sous-Marines de l'Atla	19 Inst. of Autom., Tech. Univ., Lyngby, Denmark	20 Dept. of Signals & Syst., Chalmers Univ. of Technol., Sweden	21 Project ICARE, Inst. Nat. de Recherche en Inf. et Autom., Sophia-An	22 Underwater Technol. Res. Centre, Tokyo Univ., Japan	23 Maridan AS, Horsholm, Denmark	24 Sch. of EEE, Nanyang Technol. Univ., Singapore
		# Records	17	12	12	10	8	8	8	8	8	8	8	7	7	7	6	6	6	6	5	5	5	5	5	5
1	92	Japan			12										7									5		
2	76	France																		6			5			
3	68	Italy											8													
4	56	Germany																								
5	54	China						8			8															
6	46	Portugal	17	12								8														
7	30	Russia												7												
8	26	Sweden																				5				
9	24	Spain																6								
10	21	Norway				10											6									
11	19	Belgium																	6							
12	16	Denmark																			5				5	
13	15	Netherlands								8																
14	15	Singapore							8																	5
15	13	Poland																								
16	13	Finland														7										

From the number of autonomous technology articles, the Top Institutions/Centers of Excellence in Non – TTCP Countries are identified:

1. With 17 articles, the Department of Electrical Engineering, Institute of Superior Tecnico, Lisbon, Portugal
2. With 12 articles:
    a. Faculty de Engenharia, Porto University, Portugal
    b. Institute of Industrial Science, University of Tokyo, Japan
3. With 10 articles, the Norwegian Defense Research Establishment, Kjeller, Norway,
4. With 8 articles:
    a. Depart of Underwater Acoust. Eng., Harbin Eng. Unvi,. China
    b. Sch. of Naval Archit. & Ocean Eng., Shanghai Jiaotong Univ., China
    c. Inst. of Naval Archit. & Ocean Eng., Nat. Taiwan Univ., Taipei, Taiwan

    d. Istituto per l'Autom. Navale, CNR, Genova, Italy TNO Phys. & Electron. Eng., The Hague, Netherlands
    f. Sch. Of Electr. & Electron. Eng., Nanyang Technol. Univ., Singapore
5. With 7 articles:
    a. Inst. Of Marine Technol. Problems, Acad. Of Sci., Vladivostok, Russia
    b. KDDI R&D Labs., Saitama, Japan
6. With 6 articles, the Underwater Robotics Dept., GESMA, Brest, France.

From further analysis of the articles published by these leading centers of excellence, the autonomous supporting technologies focused on by each nation can be described:

- **Portugal** - Acoustic Communications, Image / Data compression, and Coordinated control of Multiple UUVs (developmental work on **SIRENE, and MARIUS AUV**),
- **Japan** – Self-diagnosis systems for AUVs, on-line adaptation methods (developmental work **on AUV "R-One Robot", and AQUA EXPLORER**), Hybrid UUV/ROVs, Cognitive Developmental Robotics (distributive underwater and on land robots),
- **Norway** – AUV/UUV mission planning (developmental work on **HUGINS AUV**), and real time control (depth/position accuracy for seabed mapping)
- **China** - Dempster- Shafer data/sensor fusion, and Neutral Networks for motion control, Mission Planning verses sea currents, Biomimetic robots,
- **Taiwan** – AUV Control and Obstacle Avoidance (developmental work on **AUV-HM 1**),
- **Singapore** – Biomimetic Underwater Robots (developmental work on **AMOEBOT MUV, ROBOGLIDER, ROBO-EEL**), and Sensor fusion techniques for cable following (for **TWIN-BURGER 2 AUV**)
- **Italy** – AUV guidance, control and navigation systems (developmental work on the **ROMEO AUV**)
- **Netherlands** – Multi sensor and data fusion algorithm development for detecting, tracking and classification of small targets at sea (e.g., swimmers, dinghies, speedboats, and floating mines) and landmine detection,
- **Russia** - Integrated acoustical positioning system (APS) for a very long range AUV, and Solar and Wave Power AUV concept (**SAUV – Solar Powered Autonomous Underwater Vehicle**),
- **France** - Long range AUV, modular/flexible hardware, controllers (developmental work on **REDEMOR AUV**) and integrated navigation systems, and
- **Sweden** - Remote Sensing of Landmines, IR, Optical, Radar, and Biosensors for Airborne Applications

Concentration of research efforts can also be characterized by examining the data mining factor maps of combined sources using low frequency descriptors. The following technical research areas have a significant increase in emphasis over the analysis period, specifically:

a. Control system synthesis and Lyapunov methods – Used in the development of improved guidance techniques for autonomous vehicles.
b. Inference mechanisms, geometric reasoning and neural nets – Hierarchical techniques for object recognition and obstacle avoidance.
c. Edge detection and back propagation neural network – Techniques used to reconstruct images from sensors, which are used for object identification and/or guidance.
d. Dempster-Shafer framework, Bayes method and Sensor fusion – By combining complementary sensors the likelihood of detecting mines increases while the instances of false alarms decreases.
e. Gaussian noise, filtering theory and Image restoration – Used to remove noise from images to enhance detection of objects. Related techniques may also be employed to detect objects based on thermal signature differences between day and night.
f. Fuzzy cluster representation and pattern clustering – Techniques used with ground penetrating radar to detect object of interest.

CONFERENCES AND ONRIFO S&T LIAISON VISITS

The conferences (i.e., ICAR2001, UDT, Oceanology International 2002, and UUV Showcase), which ONRIFO personnel attended were arranged to cover operational results, future developments and technology challenges, embracing participation from industry, academia and defense. These conferences demonstrated the success in applying autonomous technologies to under ice operations (AUTOSUB), offshore oil industry applications (HUGINs), and offshore diamond exploration (De Beers), using unmanned vehicles. The control, navigation, and complex maneuverability of the R-One Robot (university of Tokyo) was demonstrated. Advance sensor and data fusion algorithms, compute aided classification and detection algorithms, and seafloor image display systems, were plentiful. Several miniatures AUV/ROV were also displayed, along with micro/mini robots. Presentations on development robotic swarm technologies/ networks for planetary exploration were commonplace.

ONRIFO S&T Liaison Visit to the Czech Technical University, Department of Cybernetics (http://cyber.felk.cvut.cz/), University of Ulm, Germany, Robotics Laboratory (http://smart.informatik.uni-ulm.de/), and the Helsinki University of Technology's Intelligent Machines and Special Robotics Institute (www.automation.hut.fi/IMSRI/imsri.html), provided a snap shot of the state of robotic technological developments, and unveiled two major areas of concentration:

1. Advanced bimimetics - locomotive research in lifelike systems, robotic societies/ cooperative robotics, and mobile robot swarm technologies, and
2. Neurobotics – robotics' neural network, adaptive methods towards integration of more complete task.

EXAMPLES OF INNOVATED EVOLUTIONARY DEVELOPMENTS

Most of the noted advancements are more evolutionary than revolutionary. Below are some examples:

Solar Power and Wave Energies - Russia This picture is the original design of the first Solar Power AUV. Research is ongoing to supplement solar power with wave energy, to transform wave oscillations to forward movement using three fixed wings, the demands of efficient solar powered and wave driven vehicles fully coincide.

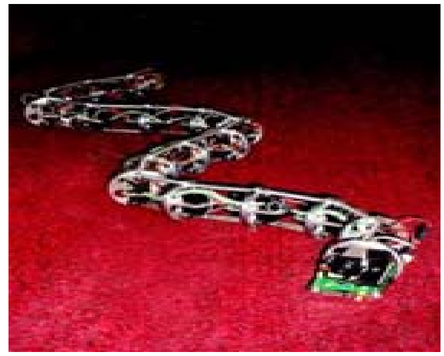
Mitsui Engineering & Shipbuilding Co., Ltd Hybrid ROV/AUV - Japan
Hybrid robot with two main functions combined i.e.; the function of non-tethered robot to navigate autonomously, to observe and monitor the underwater environment by the aid of the onboard observation equipment and the function of remotely operated underwater vehicle (ROV) to navigate by remote control by the aid of photo-electric composite cable to make a real-time observation.

The fusion of interdisciplinary technologies is fueling the development of concepts for the next generation of autonomous biosensors for rapid in-stride minefield detection.

Rats are currently being trained as **Self Reproducing Explosive Biosensors** – ***Belgium***, http://www.onrifo.navy.mil/reports/2002/101702.doc, have demonstrated olfactory capabilities to detect buried mines, coupled with the development of **The "Artificial Nose" biosensor System** - a high volume, highly selective, highly sensitive, portable and rugged vapor detection system at low cost, capable of detecting picogram levels of TNT - ***Sweden*** http://www.biosensor.se/index.html, mounted to the **•CAMCOPTER® UNMANNED AERIAL VEHICLE SYSTEM** – ***South Africa*** http://www.schiebel.com/industries/camcopter.htm could provide a rapid near real time parameterization of coastal minefields.

The words “New”, “Innovated”, “Original” and “First” are increasingly appearing in the titles of research papers published by Non TTCP countries.

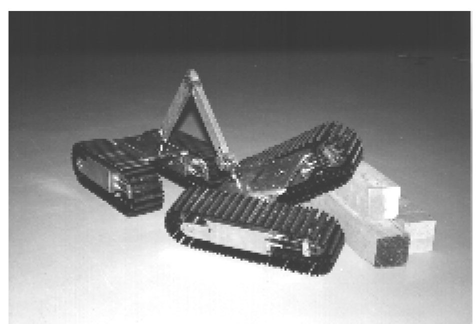
China Invents First “Snake ” Robot A Chinese designed bionic robot in the form of a real snake, made its first public show November 2001 in Changsha, capital of central China's Hunan Province. The invention is a breakthrough in China's study of the movements of robots.



It should be mentioned that most of the articles with “New”, “Innovative” or “First” embedded in the title, usually denotes that the concept is new to the publishing authors, and their associated institution, but rarely new to the scientific world. Robotic snakes have been around since the late 1980s; nevertheless the productions of the current generations of robotic snakes incorporate the latest technologies, and are highly sophisticated.

There is an increased effort in marketing multi-task, multi-capability autonomous systems. The Snake –like Robots, Walking Robots, and Wheel & Crawler Vehicles, and many other autonomous units are marketed over the Internet, and trade shows and exhibitions.

Hirose & Yoneda Robotics Lab - Japan
The Gunryu - Each segment has autonomy but at the same time it is connected with the other segments to operate cooperatively (click on image to view other robots)



TRENDS AND CONCLUSIONS

From ONRIFO conference participation, site visits, and an in-depth analysis of individual data mining articles, it can be concluded that the noted Critical & Emerging Technologies focused efforts over the years 1997-2002 were in:

1. Leading edge enabling technologies; such as remote sensors, biosensors and micro-sensors
2. System technologies such as:
    a. UUV technology; power sources, high data rate Fiber Optic & U/W acoustic comms, data compression, networked vehicles, low signatures and miniaturization of sensors and components.

b. Navigation; U/W precision positioning
c. Non acoustic, olfactory
d. Robotics; intelligent U/W and all terrain robots for mine clearanceApplication technologies such as:Simulation, 3D visualizationEnvironmental reconnaissance; remote sensing, multi-parameter measurement systems, data fusion

The above data mining results were no surprise. In fact, it could be said that the level of autonomous systems, and robot deployment is a measurement of a country's industrial strength. The identified leading Non-TTCP countries and centers of excellence were consistent with expectations. In fact, most of the TTCP government laboratories have obtained insight of ongoing activities through the discussions in open forums such as conferences, exhibitions, NATO (or Multi lateral) workshops, or via direct co-planning, co-development collaborations. However, what is revealing in this type of analysis is the pace of evolutionary developments, the expansion of applications, and the rapid proliferation of advance autonomous technologies in open sources. Open source publications of autonomous supporting technologies research results, from universities, government labs, commercial companies, and today's accessibility of the World Wide Web, are aiding the rapid proliferation of these technologies. There is an increasing network of autonomous, semi-autonomous, and robotic competitions involving universities, and high schools. These activities at the university and high school level are stimulating interest in our youths, the next generation of scientist. There even is a RoboCup Summer Camp in Germany. Robots Wars competitions can be viewed on TV. Children's books are available to build your own undersea and land robots. A derivation of the Sunfish Light Seeking AUV, (shown below) can be built for less than $50.00 dollars at your local electronics store.

Sunfish, was developed for Science World, to provide the public with an example of undersea robotics. The book next to the sunfish is a Children's book providing instruction of how to construct simple underwater robots.
www.ensc.sfu.ca/research/url/auv/sunfish.html

Fundamental concepts such as the robot snakes (mentioned above) are being revamped with modern autonomous technology to provide enhanced capabilities, and on land – at sea applications. With the variety of applications being explored, could these systems be modified and updated to deliver new mobile asymmetric threats?

Attendances and participation in international conferences and shows has increased over the analysis period. Oceanology International 2002, alone, had over 6,000 visitors from 60 countries, over 400 students from UK Universities, over 130 exhibitors drawn from 30 countries and press from 8 countries in attendance. An increasing trend exists, the mainstreaming of higher order functionality research in autonomous systems. The greater preponderance of articles addressing - Coordinated operations and control of multiple autonomous systems, long range AUV, modular/flexible hardware, integrated navigation systems. Hybrid AUV/ROVs, biomimic robots, cognitive developmental robotics, are a few examples of higher order applications and functionality.

With the proliferation of micro/mini autonomous technology, it is merely a matter of time before the emergence of new asymmetric threats from derivatives of our own technology advancements.

The Russian ANTIHELICOPTER MINE could conceptually defend against helicopter mine clearance operations.
http://www.aha.ru/~leokon/eng/index.htm

Intelligent mines and small remotely piloted vehicles, for example, may make defensive strategies easier and counter Western offensive dominance. The thrust for future collaborations with the centers of excellence (identified above) should focus on technologies to neutralize autonomous mobile mines, and re-locatable minefields.

The Office of Naval Research International Field Office is dedicated to providing current information on global science and technology developments. Our World Wide Web home page contains information about international activities, conferences, and newsletters. The opinions and assessments in this report are solely those of the authors and do not necessarily reflect official U.S. Government, U.S. Navy or ONRIFO positions.

Acknowledgement and Thanks to ONR Reserve Unit 406:
LCDR Jana H. Raymond, USNR, and CDR Charles M. Smith, USNR, for their time, assistance and support in Data mining and the analysis of the results.